function that is a linear combination of range-dependent CTQs.

[0010] In accordance with one preferred embodiment of the invention, the first stage of the design method comprises several computational blocks, several databases, and an image quality specification. The functional blocks comprise: (a) a Transducer Design Advisor to guide the creation of a parameter set; (b) an acoustic stack simulator which computes an impulse response given a specification of the layers in the probe; (c) an ultrasound beam simulator which computes acoustic diffraction given an impulse response and a definition of the aperture geometry; (d) a "scoring" package that quantifies the diagnostic value of the image simulated; and (e) a controller for controlling the simulations in accordance with a statistical design of experiment (DOE). The databases comprise a repository of material properties, including those materials suited to piezoelectric energy conversion, acoustic impedance matching, backing and focusing of acoustic beams; and an imager parameter database, containing data such as the apodization functions, focusing schedule and F-numbers for a given probe.

[0011] In accordance with the preferred embodiment, the inputs to the process are an image quality specification and some selected parameters to optimize. These parameters are chosen via the Transducer Design Advisor. The Transducer Design Advisor allows the designer to select which of the controllable parameters will be varied, and which are held constant during the various simulation runs. These controllable parameters are DOE variables. The Transducer Design Advisor also guides the selection of a suitable phantom for the simulation. A phantom is a virtual object whose function is to simulate a patient or other target for ultrasound energy. It contains simulated features of varying size, shape, location, and density of acoustic scatterers. A typical phantom might contain hyper-echoic features of small size whose purpose is to allow an assessment of the performance of the ultrasound imaging system for detecting small objects, and also hypo-echoic features to allow an assessment of system performance in detecting low-density objects. A

different phantom might provide a somewhat realistic model of a part of human anatomy.

[0012] The DOE controller varies the DOE variables in a designed experiment whose character and resolution are chosen by a DOE advisor. The DOE advisor is a small expert system that chooses the type of designed experiment appropriate for the case under study. Designed experiments allow all of the DOE variables to vary simultaneously to capture their effects on the image quality metrics, with an optimally small number of simulation runs.

[0013] In accordance with the preferred embodiment of the invention, the DOE variables and accompanying fixed parameters are presented to the acoustic stack simulator, which computes an impulse response for the current probe specification. That impulse response, together with the phantom and imager parameters, forms the input to the beam simulator. The beam simulator generates an image; it computes the diffraction of the sound from the aperture to the scatterer locations, the scattering itself, and the diffraction back to the aperture. This image can be reviewed visually (for example, on the display monitor of the user's PC) for artifacts.

[0014] For the purpose of making transfer functions, the customer value of the image is scored, based on the image quality specification. The outputs of this process are transfer functions relating each DOE variable to each image quality metric, and the DOE variables to the overall image quality. The business value of these transfer functions is threefold. First, plots of the transfer functions will aid a skilled probe designer. Second, the partial derivatives show the sensitivity of the design to manufacturing variability. Third, the transfer functions can be used to optimize the performance and robustness of the design.

[0015] The advantages of the foregoing method are manifold.

[0016] First, probe parameters, such as layer thickness and

material properties, are optimized jointly with imager parameters, such as F-numbers and focusing schedules. The advent of multi-row probes has rendered the standard practice of addressing the probe and system parameters separately wholly inadequate. This is due to the strong coupling between the two classes of parameters.

[0017] Second, deriving transfer functions explicitly has great advantages over standard design practice (evaluating the point-spread function of the imager at several values, and judging the behavior of the probe manually). Typically, the input variables are varied one at a time, which again ignores coupling of parameters. Also, a realistic number of simulations requires scanty coverage of the design space. The transfer function approach extracts the maximum information from a given computational budget, and makes sophisticated optimization techniques feasible.

[0018] Third, often the variability of image quality is almost as important as reaching a globally optimal image quality. With this method it is easy to use a program to gauge the effect of variability in system gain (due to factors such as temperature changes and/or component tolerance) and probe material properties and layer thickness variability on image quality. To do this with standard design methods requires an impractical amount of computation.

[0019] Fourth, the final result shows performance and its variance as a function of cost, which can inform the best possible management decision on product positioning.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. 1 is a flowchart showing the overall information flow for statistical design of a probe and an imager in accordance with the preferred embodiment of the invention.

[0021] FIG. 2 is a flowchart detailing the usage of transfer functions (derived using the method shown in FIG. 1) in predicting an optimal